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EFFECT OF RUBBER USAGE ON THE PERFORMANCE OF ASPHALT MIXES

تأثير استخدام المواد المطاطية على أداء الخلطات الأسفلتية

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ABSTRACT

Increasing traffic loads cause several pavement distresses such as rutting. Several trials were made to control pavement rutting by mix enhancement. These trials were already limited pavement rutting, but on the other hand showed pavement cracking as a result of lower flexibility for the modified pavements. This study aims at investigating the effect of crumb rubber on the characteristics of asphalt mixes. To achieve this objective, crumb rubber with different percentages of fine aggregate (0, 4, 8, 12, 16, 20, 24 and 28%) were used to manufacture the investigated asphalt mixes. Marshall designs were used to obtain the optimum asphalt contents and the corresponding characteristics of the investigated mixes. Other mix characteristics including Marshall stiffness, loss of stability, tensile strength as well as rutting resistance were measured for the investigated mixes. Loss of stability test, indirect tensile test (ITT) and wheel tracking test (WTT) were conducted to measure these characteristics. Analyzing the study results showed that, the use of crumb rubber has a noticeable effect on the characteristics of asphalt mixes. It is noticed that, the use of rubber percent up to 16% by weight of fine aggregate increases the pavement resistance to cracking and does not greatly affect the pavement resistance to rutting.

نتيجة لزيادة أحمال المرور على الطرق تظهر بعض عيوب الرصف مثل التخدد. ويوجد بعض المحاولات للحد من ظاهرة التخدد عن طريق استخدام المحسنات وعلى الرغم من أنها تحسن مقاومة الخلطة للتخدد إلا أنها تزيد من الشروخ في الرصف كنتيجة لزيادة جساءة الخلطة. ويهدف هذا البحث إلى دراسة إمكانية تحسين مرونة الخلطة الأسفلتية لزيادة مقاومتها للشروخ بإضافة مادة المطاط ومعالجة زيادة الجساءة الناتجة عن استخدام المحسنات التي تهدف إلى تحسين مقاومة التخدد. وللوصول إلى أهداف البحث تم استبدال جزء من الركام الناعم بمادة المطاط بنسب (٠، ٤، ٨، ١٢، ١٦، ٢٠، ٢٤، ٢٨%) وقد تم إجراء اختبار مارشال على تلك الخلطات لتحديد المحتوى الأمثل للأسفلت والخصائص الأساسية للخلطة وكذلك تم اجراء عدة اختبارات خاصة مثل اختبار الفقد في الثبات واختبار الشد الغير مباشر لمعرفة مدى مقاومة الخلطة للشروخ واختبار العجلة الترددية لقياس مقاومة الخلطة للتخدد. وقد تم تحليل نتائج البحث لكل الاختبارات والخلطات وقد أظهرت النتائج أن استخدام المطاط في الخلطات الأسفلتية له تأثير ملحوظ على خصائص الخلطة وأن استخدام المطاط حتى نسبة ١٦% من وزن الركام الناعم يزيد من مقاومة الأسفلت للشروخ كما أن ليس له تأثير كبير على مقاومة الأسفلت للتخدد.

KEYWORDS:

Crumb rubber, Asphalt mixes, Indirect tensile test, and Wheel tracking test.

1. INTRODUCTION

Increasing traffic volumes, heavier loads and poor performance of bituminous mixtures under adverse environmental conditions have led to increased use and development of modified bituminous binders and asphalt mixtures. The types of modifiers that have been used include sulphur, rubbers, thermoplastic polymers and thermosetting resins; the main objective is to improve the mechanical properties under all service conditions [1]. Many countries around the world are facing many challenges regarding their waste materials [2]. One of the worrying waste problems is how to deal with scrap tires. However, the improvement of asphalt pavements and waste recycling can be to solve together. Many approaches have been considered for treating and improving asphalts binders through the incorporation of the crumb rubber from waste tires in it, called, asphalt rubber. Besides the ecological solution, tire recycling has the great economical importance and the enhancement of the properties of the asphalt when apply in asphalt mixtures such as better fatigue and permanent deformation performance have been proved. In addition the use of asphalt rubber is indicating in tropical countries, where the normal temperature in summer time will make the asphalt material become softer that reduce the service life of the road [3]. It is of a great importance to notice that, using asphalt additives to mix components will already increases mix stiffness and stability which in tern give higher resistance to rutting. On the other hand, increasing mix stiffness will already increase pavement cracking especially in hot climatic conditions. Some studies tried to use crumb rubber to discover its ability to resist cracking distresses. It is believed that, using rubber increase mix stiffness and in turn minimizes pavement cracking [4]. So, the objective of this study is to investigate the influence of rubber percent on the characteristics of paving mixes and to identify the allowed percent of rubber that not adversely affect mix characteristics.

2. EXPERIMENTAL DESIGN

The design of experiment of this study is concerned with using the crumb rubber instead of fine aggregate by different percentages. Eight different percentages are considered. They are 0, 4, 8, 12, 16, 20, 24 and 28%. The selected mix gradation is 4C and corresponding specification limits are shown in Table (1). Also the experimental design concerned with selecting the appropriate tests most related to evaluating paving mixes performance. Marshall test was performed to measure optimum asphalt content (OAC) and routine mix characteristics. Indirect tensile test was selected to assess tensile strength for fatigue cracking resistance while wheel tracking test was selected to evaluate rutting tendency of investigated mixes.

3. MATERIALS

To achieve the objective of this study, one type and source for each of the mix components is chosen to eliminate the effect of their variations on the mix properties. The coarse part of the aggregate is a crushed dolomite obtained from "ATAKA" quarry, Suez Governorate. The results of its qualification tests are presented in Table (2). Siliceous sand with bulk specific gravity of 2.65, obtained from "Fayed" quarry, Ismailia Governorate and limestone mineral filler of bulk specific gravity of 2.85 are used as the fine part of the mix. Their gradations are shown in Table (3). Suez asphalt cement (60/70-penetration grade) of 1.02 specific gravity was used as a binder with the properties shown in Table (4). The used rubber is the scrap rubber tires converted to rubber chips or crumb rubber and its gradation is shown in Table (5).

4. TESTING PROGRAM

Three major tests were conducted through the laboratory-testing program of this study. These tests are the standard Marshall test including loss of stability test, indirect tensile test and wheel tracking test.

4.1 Marshall Test

In order to find the Optimum Asphalt Contents (OAC's) and the corresponding physical properties (air voids, voids in mineral aggregate and unit weight) as well as mechanical properties (stability, flow and Marshall stiffness; M_s) for the investigated mixes, Marshall mix design procedure was performed. The test criterion selected was for a 75-blow Marshall compaction according to ASTM D1559 and AASHTO T-245 [5, 6].

4.2 Loss of Stability Test

Loss of stability test, which is simplified version of AASHTO-T165 was used to measure mix durability by evaluating the resistance of the investigated mixes to moisture damage. This test is intended to measure the loss of stability resulting from the action of water on compacted asphalt mixtures by comparing the stability of dry specimens to the stability of specimens which have been immersed in water bath at 60^oC for certain times; 1, 2 and 3 days.

4.3 Indirect Tensile Test

Indirect tensile test was carried out to measure indirect tensile strength (σ_t) as an indicator for cracking susceptibility. The test was conducted at room temperature (30^oC) by loading test specimens (Marshall specimen) with compressive vertical load that act parallel to and along the vertical diameter plan until failure at constant rate of loading of 0.04 in/min. Steel loading strip 0.5 inch wide with a curved loading surface was used to distribute the load uniformly and to maintain a constant loading area. The indirect tensile strength (σ_t) measured from this test was calculated using the simplified equation developed by Kenndy [7] for 4.0 inch diameter specimen as follows:

Indirect Tensile Strength (σ_t), psi = 0.156 (P_f / H)

Where:

P_f = Total load at failure, 1b

H = Height of specimen, in

4.4 Wheel Tracking Test

The wheel tracking technique is a simulative rutting test conducted on specimens with dimensions 44.40 cm x 33.40 cm x 5 cm to evaluate rutting of asphalt paving mixes. The test was performed at the standard test temperature in Egypt of 60^o C under a controlled stress of 0.60 MPa gained from the wheel tracking machine with a pneumatic tire which is rolled on the slab at 42 passes /min for a period of one hour. It is of a great importance to notice that the test specimens were prepared with optimum asphalt content defined by Marshall design method. The track depth (rut depth) was measured continuously as a function of time every 5 minutes intervals. The wheel tracking technique was developed by British Road Laboratory [8].

5. ANALYSIS OF RESULTS

The routine mix characteristics (optimum asphalt content, unit weight, stability, flow, air voids and voids in mineral aggregate) according to Marshall test as well as indirect tensile strength and the creep strain of the investigated mixes are shown in Table (6).

5.1 Marshall Test Results

The results of Marshall test of mixes having different percentages of rubber are presented in Figures (1 to 7). The figures indicate that increasing of rubber percent from 0 to 28%, slightly decreases optimum asphalt content, air voids, unit weight, Marshall stability and stiffness, while Marshall flow and voids in mineral aggregate slightly increase. It can not ignored that, the stability value of the mix with rubber percent = 28% is still accepted according to Road and Bridges Authority (stability >1800 Ib).

5.2 Loss of Stability Test Results

The loss of stability test results are presented in Table (7). The loss of stability values versus time of the investigated mixes having different percentages of rubber are shown in Figure (8). For all mixes, the loss of stability increases as immersion time increases with decreasing rate. Examining Figure (8), the superiority of the mixes with low percent of rubber up to 12% in resisting moisture damage (stability loss < 20%) can be noticed. On the other hand, the mix with percent of rubber = 16% exhibits grater loss of stability with time, followed by the mix with percent of rubber = 20, 24 and 28%. The mix with rubber percent = 12, 16, 20, 24 and 28% exhibits 0.63, 0.55, 0.43, 0.39 and 0.35 times resistance to moisture damage grater than the mix with rubber percent = 0%, respectively. Based on loss of stability results, it can be concluded that, the allowed range of percent of rubber is < 16%.

5.3 Indirect Tensile Test Results

The results of indirect tensile test of mixes having different rubber percentages are presented in Figure (9). It can be seen from the figure that, the indirect tensile strength (σ_t) slightly increases up to rubber percent =16% , then it sharply decreases from rubber percent > 16% and up to 28%. Based on this analysis results, the mix with rubber percent =16% is the most preferable mix because the main goal of using rubber in the asphalt mixtures is to increase pavement flexibility and therefore pavement resistance to cracking.

5.4 Wheel Tracking Test Results

The wheel tracking test results are presented in Table (8). The values of rut depth versus time of mixes having different rubber percentages are shown in Figure (10). For all mixes the rut depth increases as loading time increases with decreasing rate. Examining Figure (10), the superiority of the mixes with low rubber percent up to 16% in resisting deformation can be noticed. On the other hand, the mix with rubber percent = 20% exhibits grater deformation with time, followed by the mix with rubber percent = 24 and 28%. The mix with rubber percent = 0% exhibits 1.6, 2.2, 2.3 and 2.4 times resistance to deformation grater than the mix with rubber percent =16, 20, 24 and 28%, respectively. Based on this analysis results, it can be seen that, the use of rubber percent up to 16% of fine aggregate does not greatly affect the pavement resistance to rutting.

Considering all investigated mix properties together (Marshall properties, moisture damage, tensile strength and rut depth) with respect to rubber percent, it can be concluded that, the accepted value of rubber percent for superior performance of their mixes in the field is 16%.

6. CONCLUSIONS

Based on the methodology and the analysis of results of this study, the following conclusions were drawn:

1. Optimum asphalt content, air voids, unit weight, Marshal stability and stiffness decrease as rubber percent increases.
2. Mix flow and voids in mineral aggregate increase as rubber percent increases and this may enhance pavement resistance to rutting.
3. The loss of stability is in the acceptable range(<20%) when using rubber percent up to 16% of fine aggregate.
4. Increasing rubber percent from zero to 16% by weight of fine aggregate increases the indirect tensile strength. This greatly enhances the pavement resistance to cracking.
5. The use of rubber percent up to 16% by weight of fine aggregate does not greatly affect the pavement resistance to rutting (0.02" to 0.03").

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6. Based on the study results, a proposed mix is prepared with 16% rubber by weight of fine aggregate.

7. RECOMMENDATIONS

Based on the study results and the drawn conclusions, the following recommendations are suggested:

1. Using of rubber material in manufacturing asphalt concrete mixtures is recommended to enhance cracking resistance of the pavement.
2. Using rubber percent of 16% by weight of fine aggregate gives satisfactory properties of asphalt mix, which in turn would provide optimum field performance and limit pavement cracking by a considerable extent.
3. Other materials such as rubber and slag should be investigated in production of asphalt mix to overcome some dangerous pavement distresses.
4. Indirect tensile test (ITT) and wheel tracking test (WTT) should be incorporate into the current mix design methods in addition to Marshall mix design method.

8. REFERENCES

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Table (1): *Gradations of the Investigated Mixtures*

Sieve Size	Designed Gradation	Spec. Limits of 4C
1 in	100	100
3/4 in	90	80 - 100
1/2 in	78	-
3/8 in	70	60 - 80
No.4	56.3	48 – 65
No.8	42.5	35 – 50
No.16	33	-
No.30	25	19 – 30
No.50	17	13 – 23
No.100	11	7 – 15
No.200	5	3 – 8

Table (2): *Properties of Coarse Aggregate Material*

Test No.	Test	AASHTO Designation No.	Results	Specification Limits
1	Specific Gravity(S.G); - Bulk S.G - Saturated surface-dry S.G - Apparent S.G	T-85	2.523 2.542 2.664	- - -
2	Water absorption (%)	T-85	2.88	≤ 5
3	Disintegration (%)	T-112	0.72	≤ 1
4	Los Angeles Abrasion; -After 100 rev. (%) -After 500 rev. (%)	T-96	6.5 26	≤ 10 ≤ 40
5	Stripping (%)	T-182	> 95	≥ 95

Table (3): *Gradations of Fine Materials*

Sieve Size	Percent Passing		Specification Limits for Mineral Filler
	Siliceous Sand	Mineral Filler	
No.4	100		
No.8	95		
No.16	84		
No.30	64	100	100
No.50	21	95	-
No.100	3.5	88	≥ 85
No.200	1.5	70	≥ 65

Table (4)*: Properties of Bituminous Material*

Test No.	Test	AASHTO Designation No.	Results of AC 60/70	Specification Limits of AC 60/70
1	Penetration (at 25 oC), 0.1 mm	T-49	63	60 - 70
2	Softening point, oC	T-53	52	45 - 55
3	Flash point, oC	T-48	+270	≥ 250
4	Kinematic Viscosity (at 135 oC), Cst	T-72	353	≥ 320
5	Ductility, cm.	T-51	+100	≥ 95

Table (5): *Gradation of Used Rubber*

Sieve Size	Percent Passing
No.4	100
No.8	98
No.16	84
No.30	56
No.50	37
No.100	12
No.200	0.4

Table (6): *Marshall Test Results and Corresponding Mix Characteristics*

Rubber %	**AC %**	**γ gm/cm^3**	**Stability Ib**	**Flow 0.01''**	**AV %**	**VMA %**	**Ms* Ib/in^2**	**σ_t** Ib/in^2**
0	5.60	2.405	2826	8.85	4.5	14.0	12773	39
4	5.56	2.397	2790	9.95	4.3	14.6	11216	42
8	5.53	2.380	2688	11.25	4.2	14.8	9557	46
12	5.50	2.373	2540	12.00	3.9	15.5	8467	49
16	5.45	2.361	2445	13.10	3.8	16.2	7466	55
20	5.42	2.352	2385	15.25	3.6	16.7	6256	50
24	5.40	2.340	2205	17.00	3.0	17.5	5188	42
28	5.30	2.330	2010	18.50	2.3	18.2	4346	35

* Ms: Marshall stiffness = (stability/flow)/specimen thickness

** σ_t: Indirect tensile strength

Table (7): *Loss of Stability as Percent of Original Stability*

Rubber% / **Time, days**	0	4	8	12	16	20	24	28
0	0	0	0	0	0	0	0	0
1	6	8	10	11	13	15	17	18
2	10	12	14	15	17	21	27	29
3	12	14	17	19	22	28	31	34

Table (8): *Observed Track Depth (WTT)*

Rubber% / **Time, min**	0	4	8	12	16	20	24	28
0	0	0	0	0	0	0	0	0
5	1.20	1.30	1.40	1.80	2.20	2.70	3.00	3.20
10	1.70	1.80	2.30	2.40	3.10	3.60	3.90	4.10
15	2.30	2.50	2.80	3.10	3.70	4.30	4.80	5.00
20	2.90	3.20	3.30	3.60	4.00	4.90	5.60	5.80
25	3.30	3.50	3.80	4.00	4.40	5.40	6.50	6.80
30	3.60	3.80	4.10	4.50	4.80	5.80	7.10	7.50
35	3.70	4.00	4.30	4.80	5.20	6.20	7.60	7.90
40	3.80	4.20	4.50	5.00	5.40	6.80	8.00	8.20
45	3.90	4.30	4.70	5.30	6.00	7.40	8.50	8.80
50	3.95	4.40	4.80	5.50	6.30	7.70	8.80	9.20
55	4.00	4.50	4.90	5.60	6.40	8.20	9.10	9.60
60	4.10	4.60	5.00	5.70	6.60	8.90	9.30	9.90

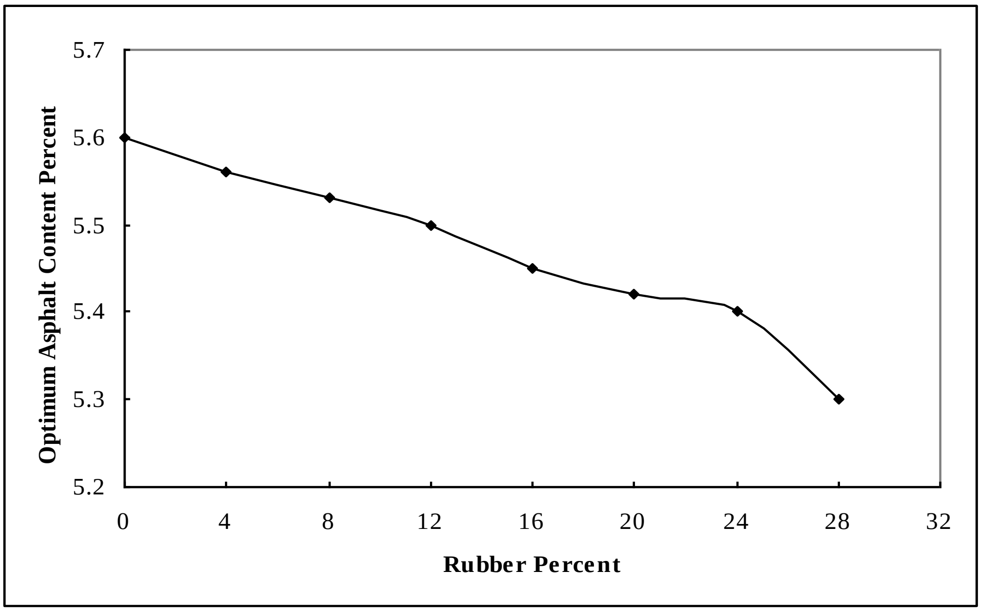

Figure (1): *Relationship between Rubber Percent and Optimum Asphalt Content*

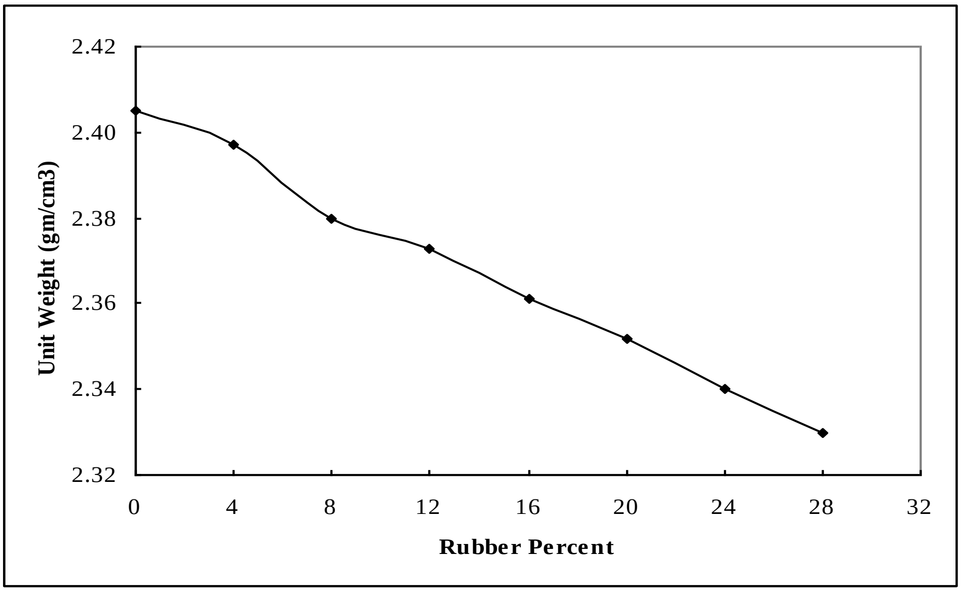

Figure (2)*: Relationship between Rubber Percent and Unit Weight*

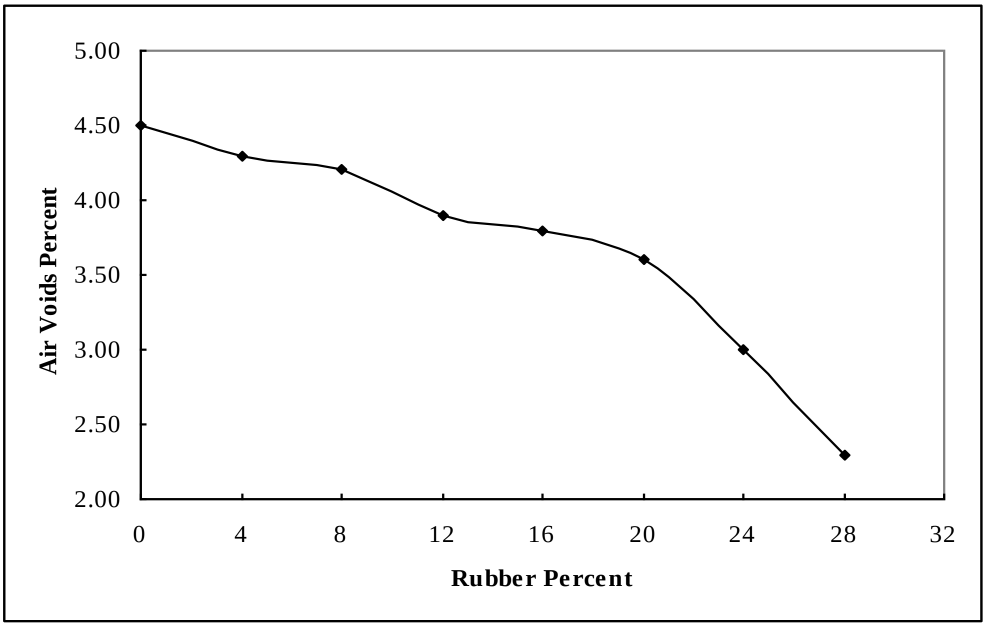

***Figure (3)**: Relationship between Rubber Percent and Air Voids*

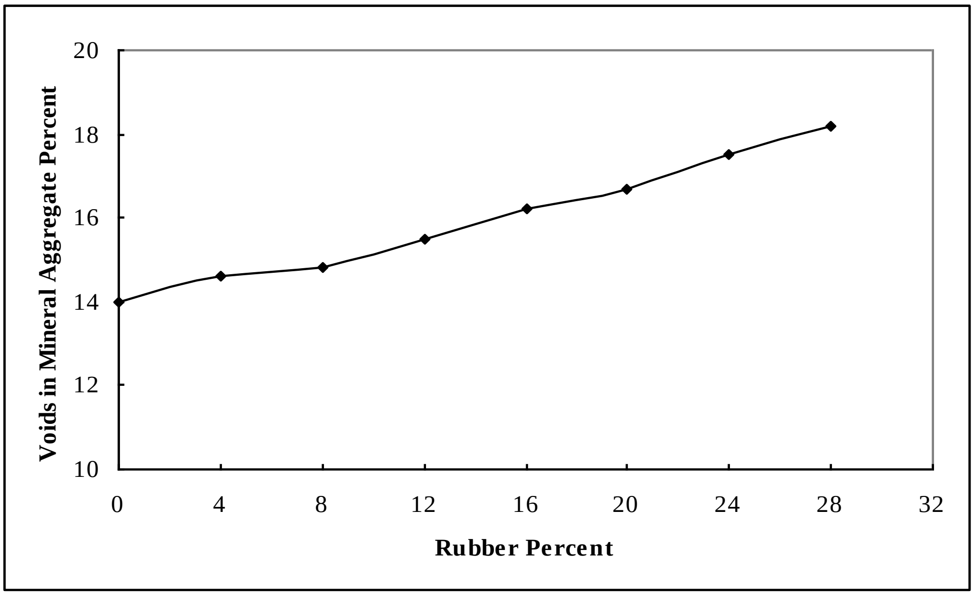

***Figure (4):** Relationship between Rubber Percent and Voids in Mineral Aggregate*

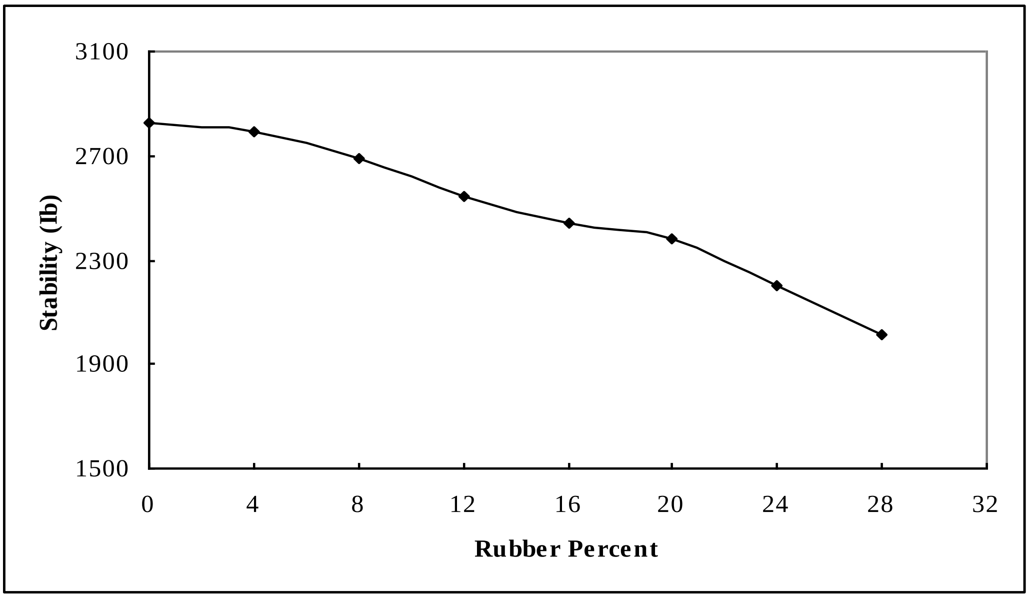

Figure (5): *Relationship between Rubber Percent and Marshall Stability*

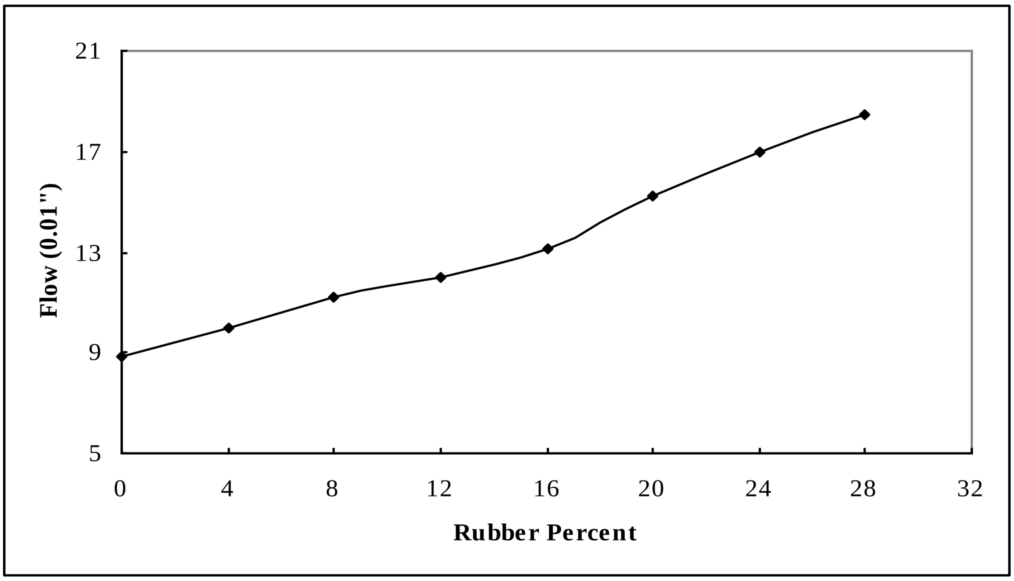

Figure (6): *Relationship between Rubber Percent and Mix Flow*

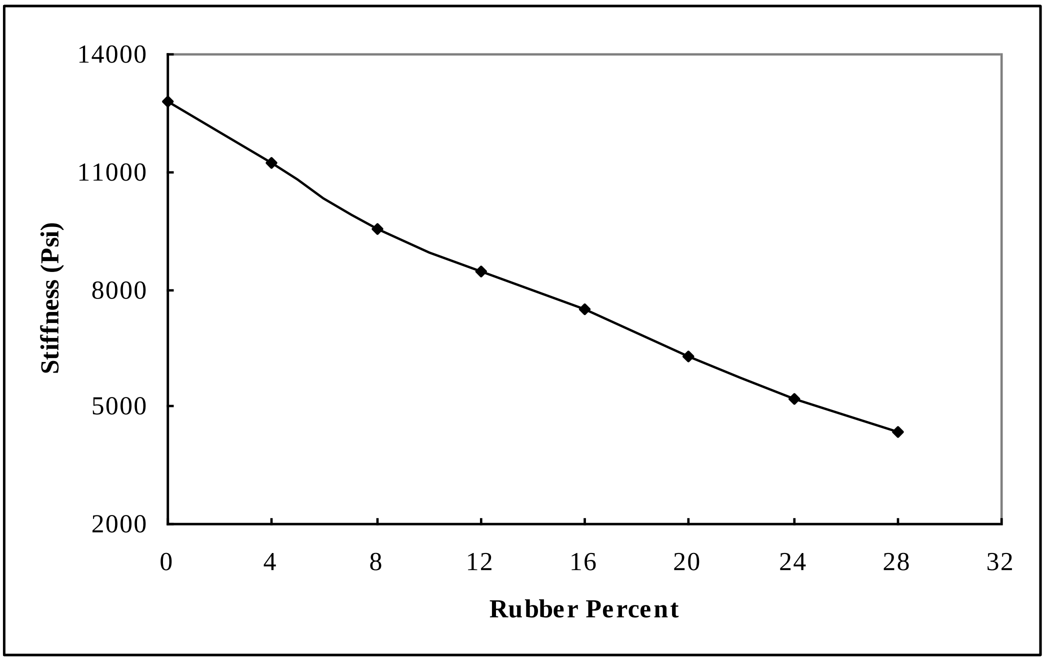

Figure (7): *Relationship between Rubber Percent and Marshall Stiffness*

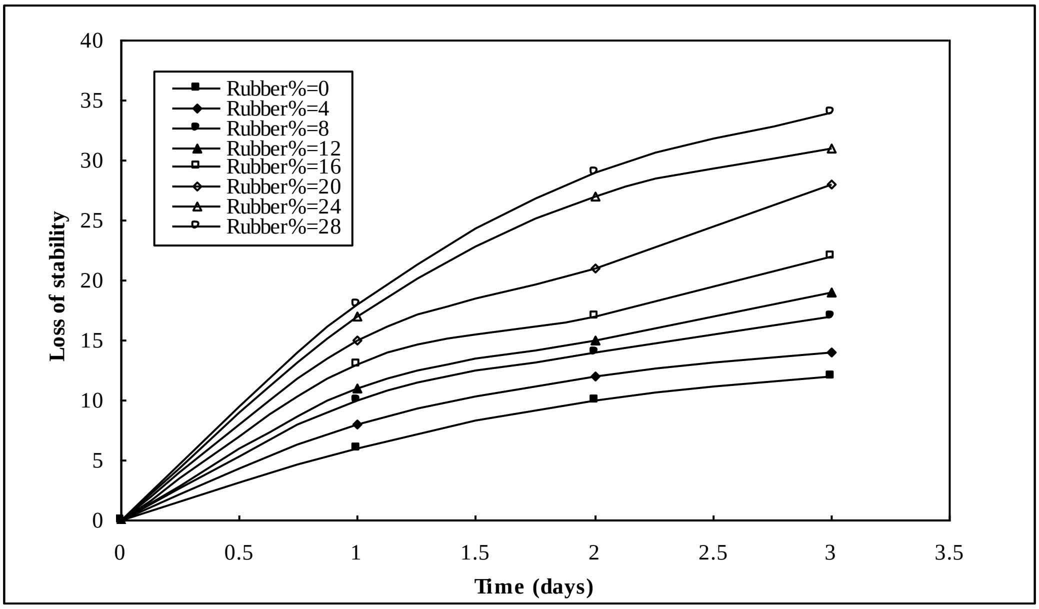

Figure (8): *Relationship between Loss of Stability and Time for the Investigated Mixes*

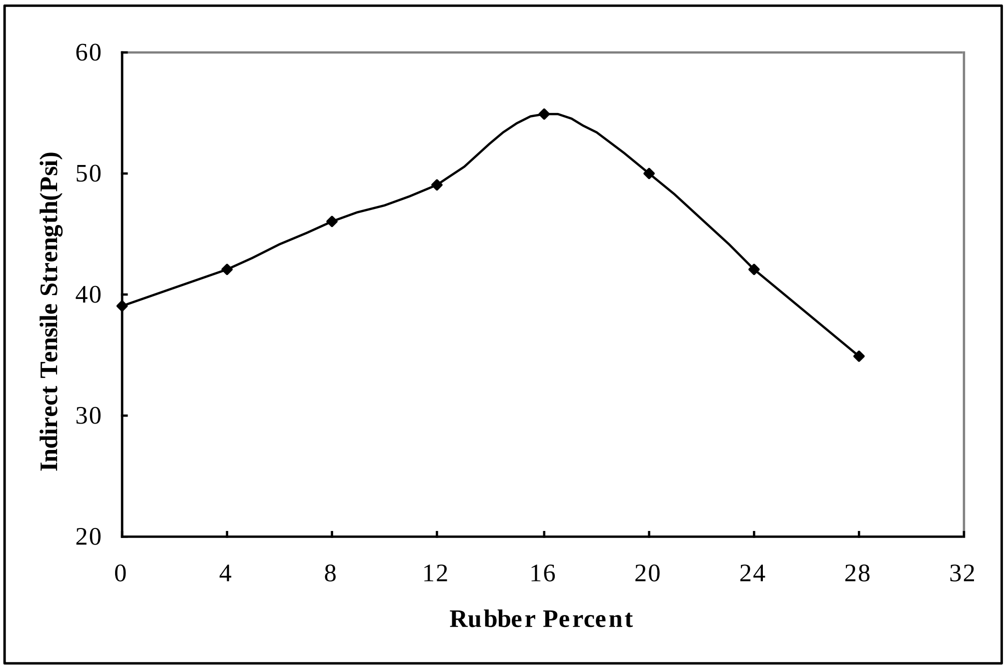

Figure (9): *Relationship between Rubber Percent and Indirect Tensile Strength*

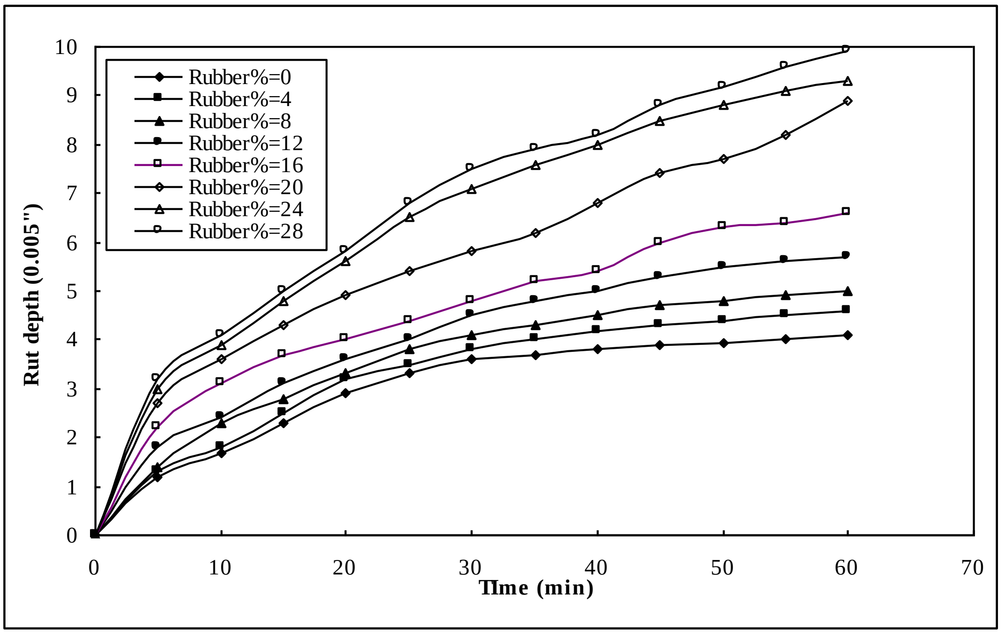

Figure (10)*: Relationship between Rut Depth and Time for the Investigated Mixes*